L0: COURSE OVERVIEW & INTRO TO IOT

ESE516: IoT Edge Computing

Wednesday, January 16, 2019

Eduardo Garcia

edgarc@seas.upenn.edu

WHO AM I?

Electrical Engineer

Bresslergroup

Developing solutions for a range of clients, from small startups to large medical device companies.

Work in all stages of project life, from ideation all the way to production.

www.bresslergroup.com

EDUARDO GARCIA

BRESSLERGROUP

TEACHING STAFF

Responsible for electrical CAD and firmware assistance.

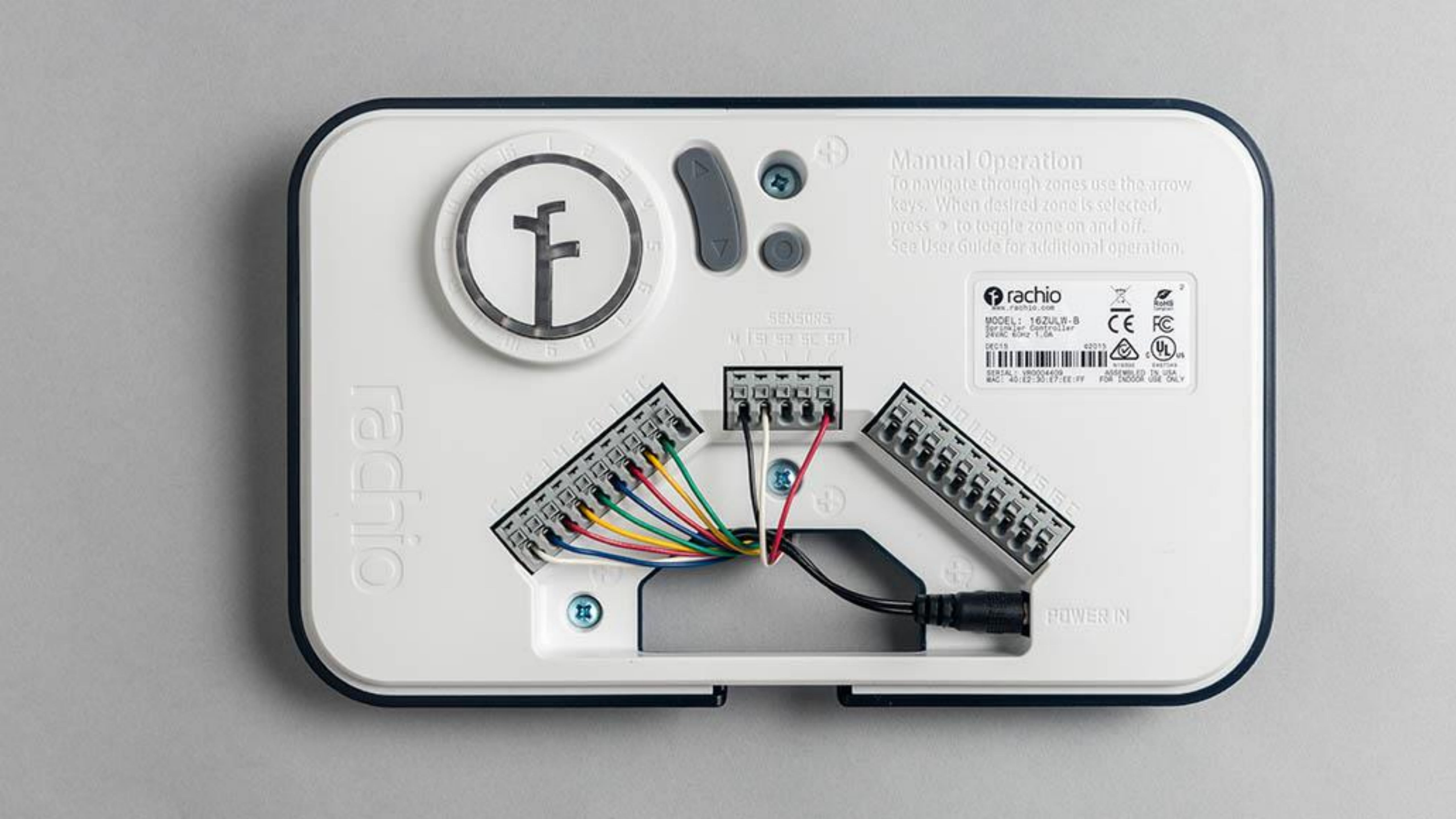
Will be running office hours in Detkin Lab (TBD)

Samyukta Ramnath

Chandana Bathulapalli

Sourav Bandyopadhyay

Vedashree Rawalgaonkar


Manual Operation
To navigate through zones use the arrow keys. When desired zone is selected, press ⊙ to toggle zone on and off.
See User Guide for additional operation.
rachio
www.rachio.com
MODEL: 16ZULW-B
Sprinkler Controller
24VAC 60Hz 1.0A
ASSEMBLED IN USA
FOR INDOOR USE ONLY
SENSORS
POWER IN
rachio


VICTOR®


AIR pod
TEMPTU air

WHO ARE YOU?

- Please complete (very short) survey for Friday January 18th 2019
  - Will be put on Piazza
- Undergraduates? Graduate students?
- Embedded Masters? EE undergrad? Other degree?
- Why are you taking this course?
- What do you want to take out of this course

COURSE OVERVIEW

WHAT IS IOT?

Internet of Things

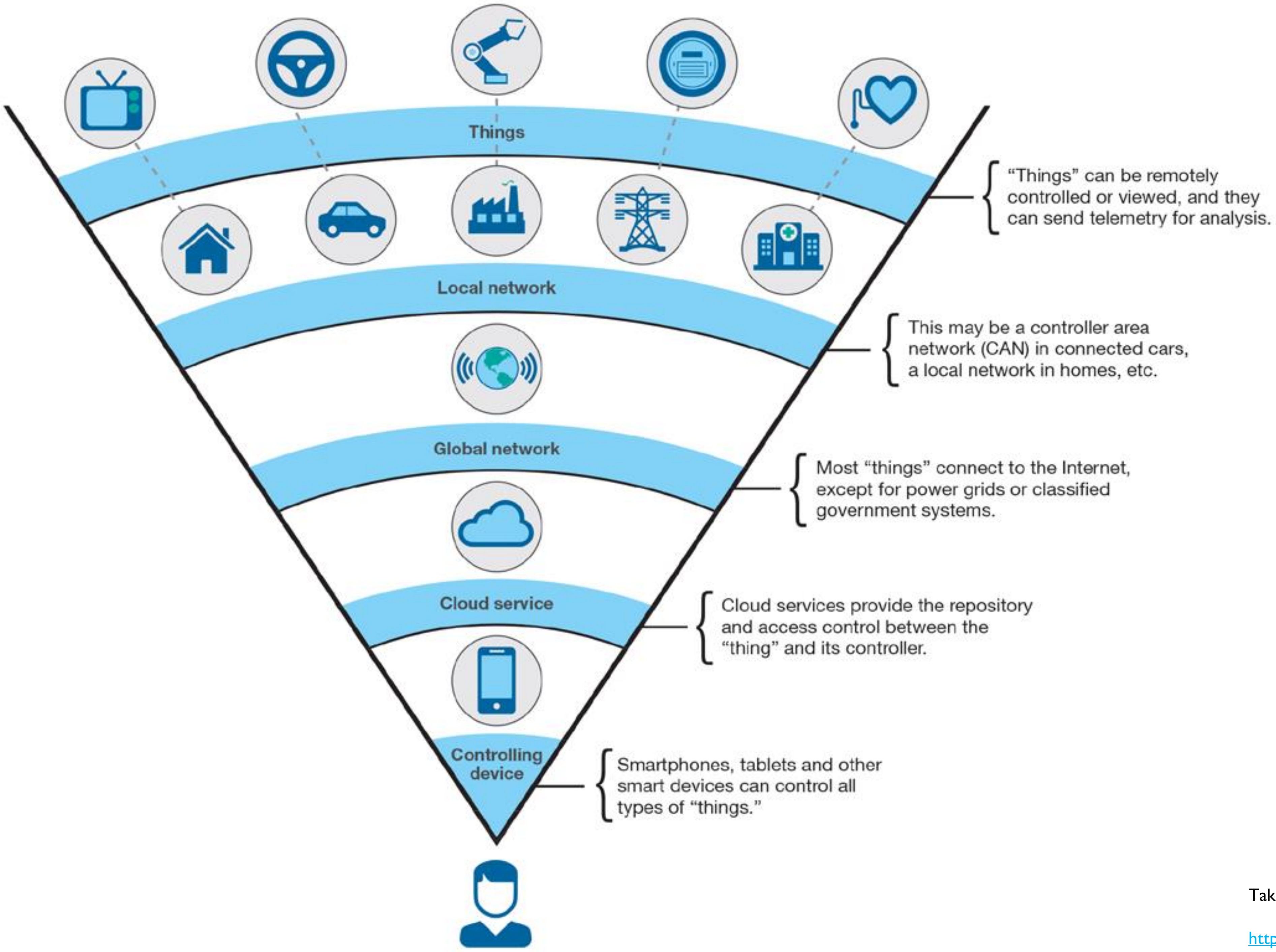
Network of physical objects connected to other devices and systems via the internet.

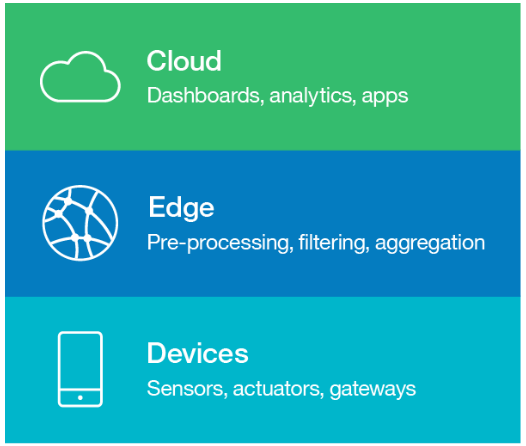
- Objects share information with other components via the internet
- Objects can have sensors and/or actuators
- Functionality of the objects is augmented due to this communication with other objects and/or systems

CONNECTIVITY IS A NECESSITY

Devices communicate to the internet one way or another

In general, if you're intending to work in the embedded space, you should be prepared to develop for these systems!

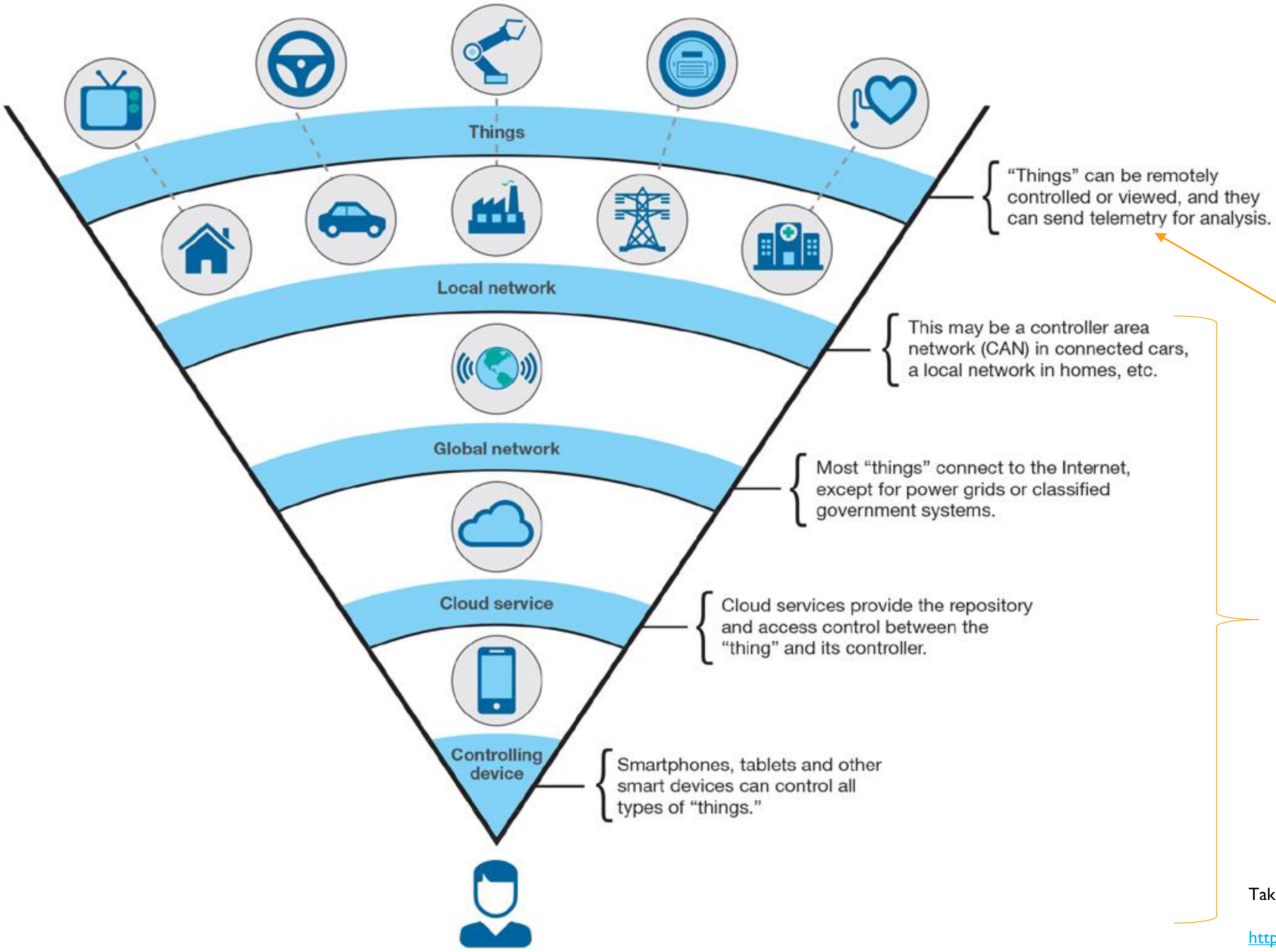




Taken from:

https://developer.ibm.com/articles/iot-lp201-iot-architectures/

Class objective in a Nutshell



How to design effective IoT embedded devices…

…That can effectively be introduced into an IoT Ecosystem

Taken from:

https://developer.ibm.com/articles/iot-lp201-iot-architectures/

COURSE OBJECTIVES

- This class aims to teach a general overview on the design of IoT products from an EE perspective:
  - **Hardware (HW)**
    - Hardware Design considerations for IoT devices
    - Component Selection and Power Budget
    - Circuit Design
    - Circuit Board Layout and Fabrication, DFM considerations
  - **Firmware (FW)**
    - Develop common embedded devices blocks
      - Command-Line Interface (CLI)
      - Sensor and /or Actuator FW development
    - Bootloader for Firmware Updates
    - Internet connectivity
      - Over the Air Firmware Upgrade (OTAFU)
      - Cloud connectivity and communication by MQTT

OUT OF SCOPE FOR CLASS

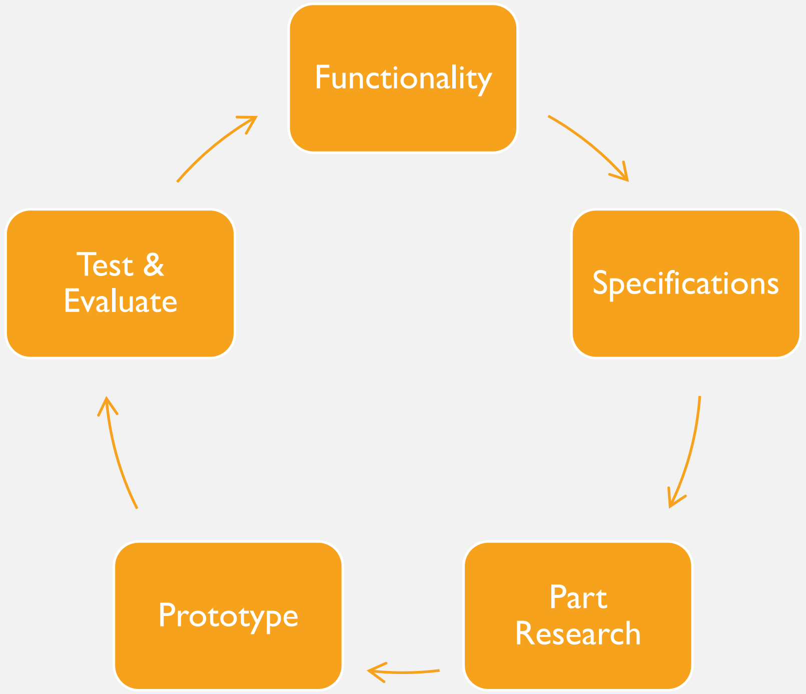
- No systems based on Linux, Android or RTOS will be seen
  - No rPI or similar boards running Linux or Android
  - Our system will be running "bare-metal" C
    - Brush up your embedded C!
- The class is an overview on design of IoT Products
  - We will not have examples for all the IoT frameworks out there (AWS, IBM Watson, Microsoft Azure, Google Cloud Platforms, etc.)
- Security in IoT devices will be explained, but due to time constraints will not be added into projects.

HIGH LEVEL COURSE PLAN

- This is a project based class!
- We will design and build an IoT device
  - …Following good industry practices (HW and FW)
  - …Developing building blocks necessary for successful device integration with the cloud (HW and FW)
  - …using industry tools

HIGH LEVEL COURSE PLAN

We will design and build an IoT embedded device by running through a (simplified) product design cycle



HIGH LEVEL COURSE PLAN

We will design and build an IoT embedded device by running through a (simplified) product design cycle

Phase 1	**Phase 2**	**Phase 3**
Design & Fabricate Device	Develop OTAFU Bootloader	Sensors + Cloud + Integration

HIGH LEVEL COURSE PLAN

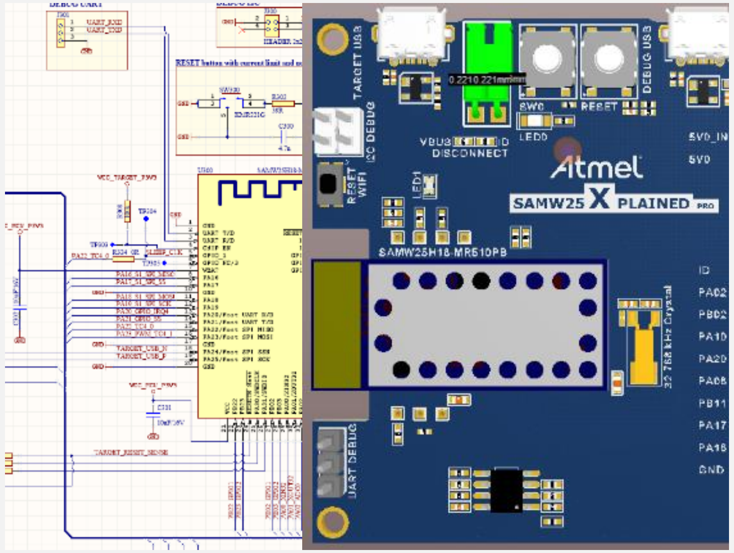
We will design and build an IoT embedded device by running through a (simplified) product design cycle

Phase 1	Phase 2	Phase 3
Design & Fabricate Device	Develop OTAFU Bootloader	Sensors + Cloud + Integration
A0,A1,A2,A3,A4,A5,A6	A7,A8	A2,A9,A10,A11

PHASE 1: DESIGN & FABRICATE DEVICE

Objectives:

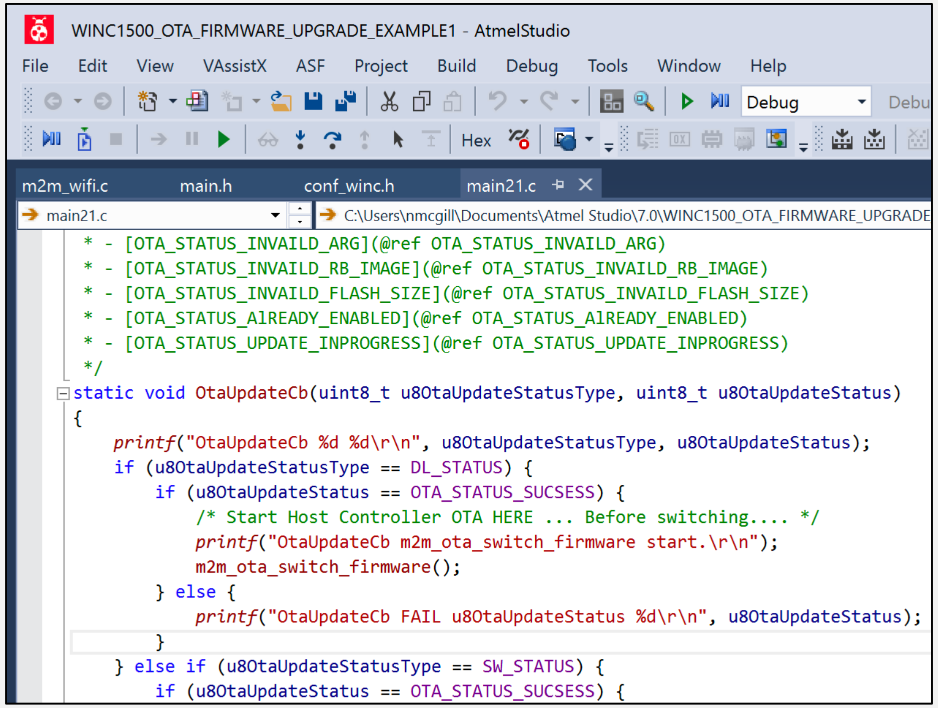
- Design the product - obtain requirements
- Product Design and Feasibility
  - Component Selection
  - Power Budget
  - Bill of Materials
- Circuit Design
- Board Design



PHASE II: DEVELOP OTAFU BOOTLOADER

Objectives

- Design & implement an over the air firmware update (OTAFU) bootloader
  - Common piece in any IoT device – Better to do it from the start!



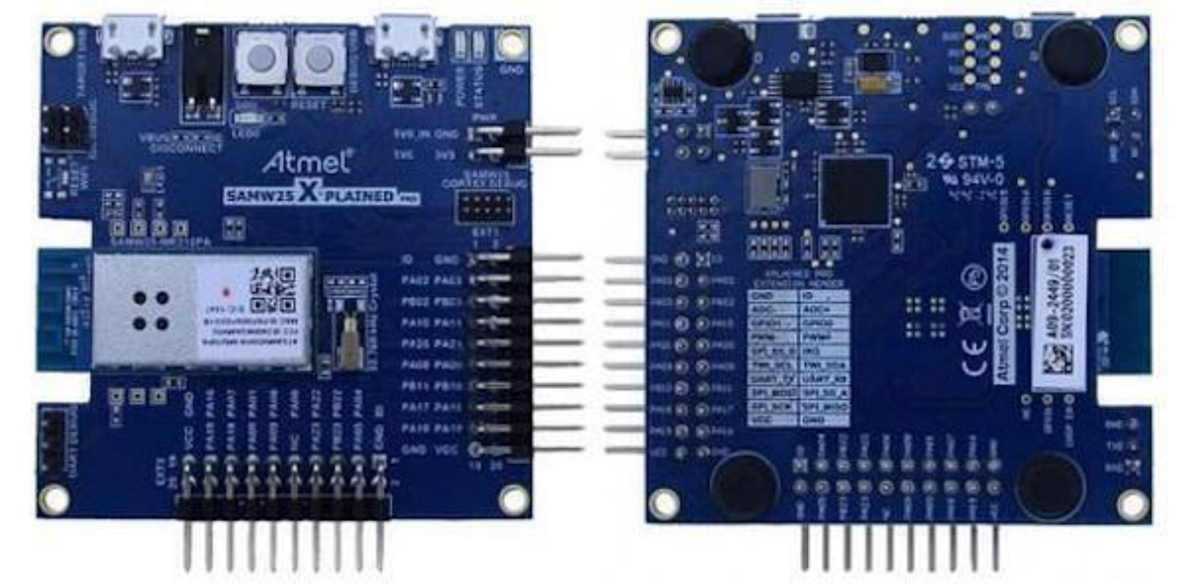
PHASE III: SENSORS + CLOUD + INTEGRATION

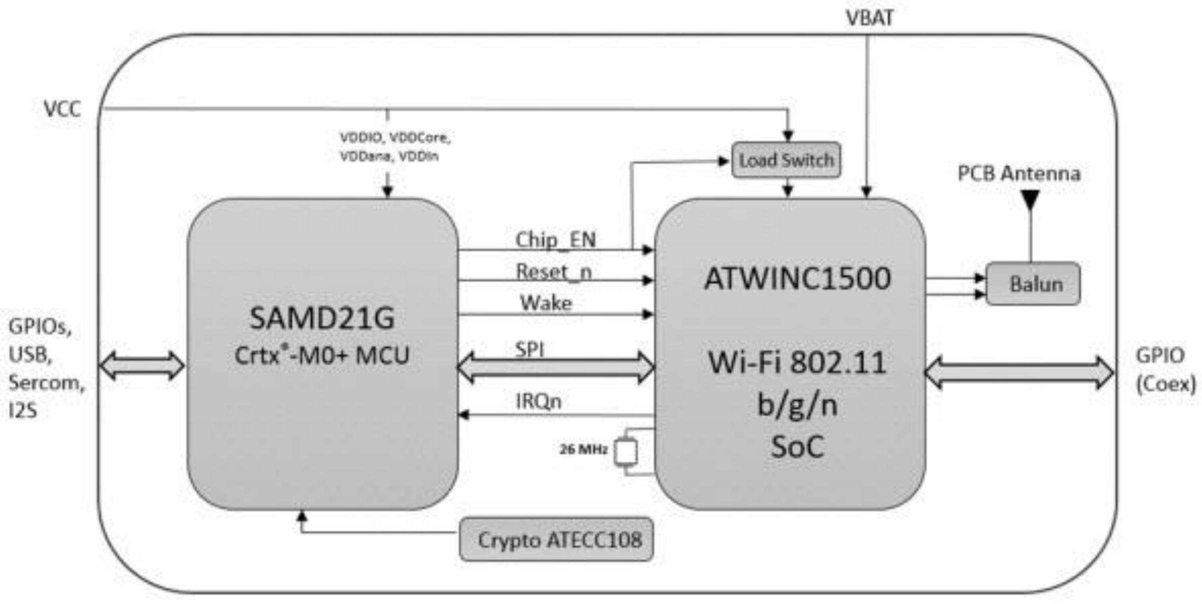
Objectives

- Write the product firmware needed to allow the product to performs its tasks
  - Sensor/Actuator integration
  - Application Code (main activities the product does)
  - Cloud integration
- Integrate code to finished hardware

SAM W25

- It's a **module** that combines:
  - **SAMD21:** Cortex M0+
  - **ATWINC1500:** WiFi
  - **ATECC108:** Hardware crypto chip
- FCC certified!
- We'll be testing with a SAMW25 Xplained development board
  - This dev board includes an EDBG chip, allowing flashing and debugging with Atmel Studio





GRADING

- This course is hands on. All grading will be based on the project assignments.
- The entirety of the course will be done in groups of two.
- Your individual participation throughout the course will be taken into account during grading.
- There will be no exams in this course.

TOOLS

- Required by students:
  - Your own computer, capable of running Atmel Studio 7
    - Windows only, sorry!
    - Apple, Linux- May need Parallels or VMWare
  - Video recording device, such as a cell phone
- Provided:
  - Altium ECAD – available on Detkin & Ketterer Lab computers
  - MicroChip / Atmel SAM W25
  - Atmel-ICE Debugger

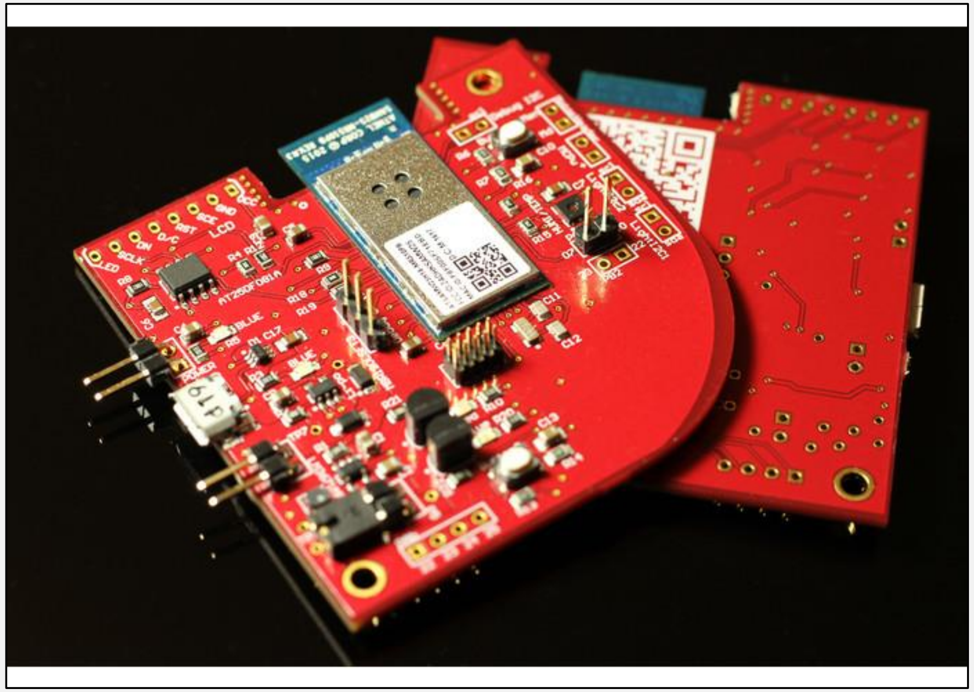
LOGISTICS

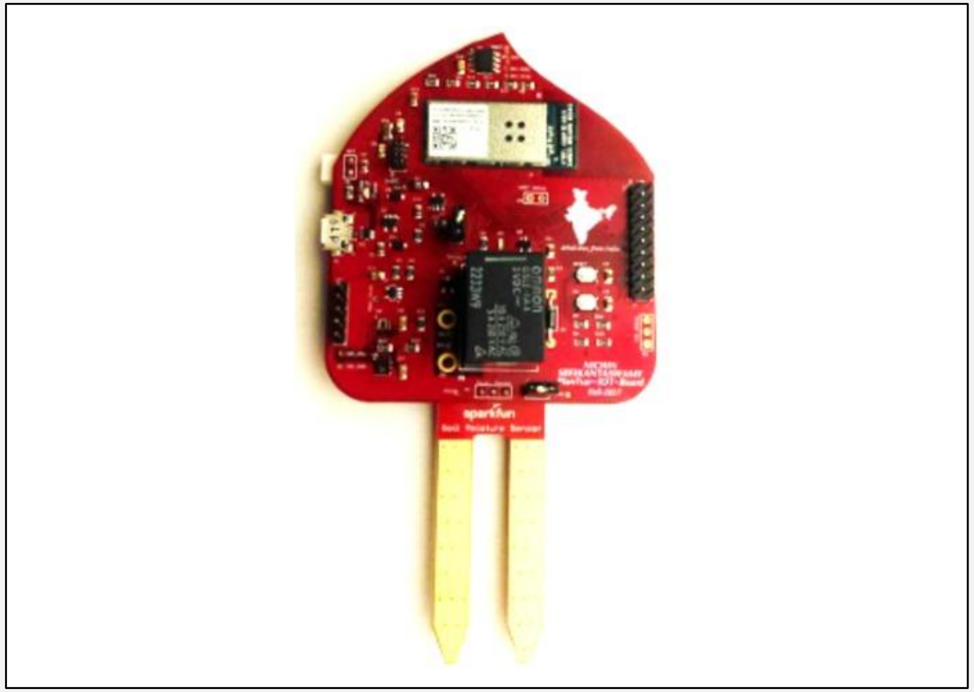
- All classes will be held in Ketterer Lab
  - Contact Shveta if your access is not working for either Ketterer or Detkin labs.

- **Communications:** Piazza
- **Course related questions:** Piazza
- **Submissions:** Google Drive group folder
- **Grading:** Canvas
- **Personal questions:** sent to my email
  - edgarc@seas.upenn.edu
- Course related questions will not be answered through email, only on Piazza.

CONCEPTS

LAST YEAR'S CLASS





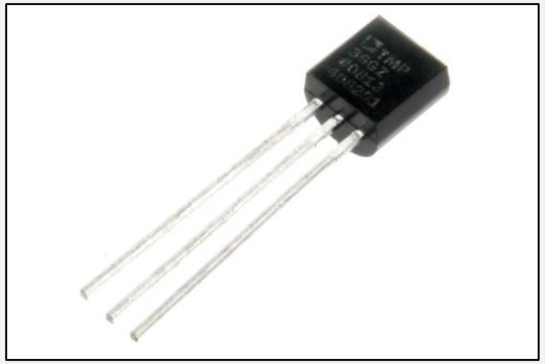
https://ese680as17.devpost.com/submissions

CHRONOSOCK

23:59:59

SOUS VID(IOT)


CROCK·POT
Off
Low
High
Warm

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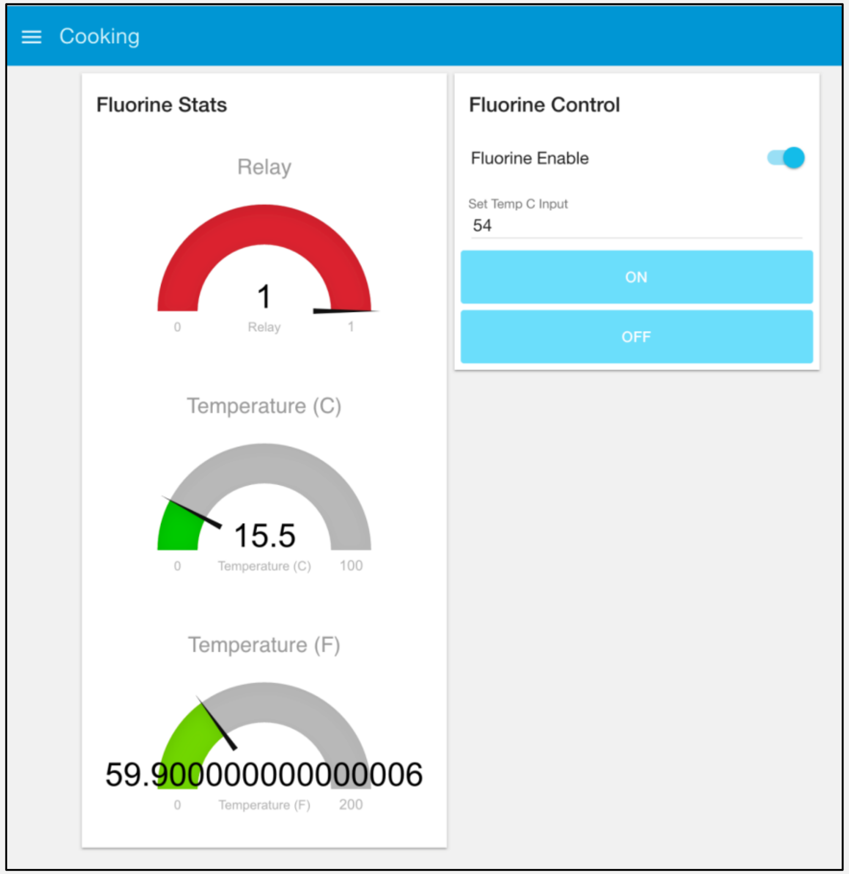
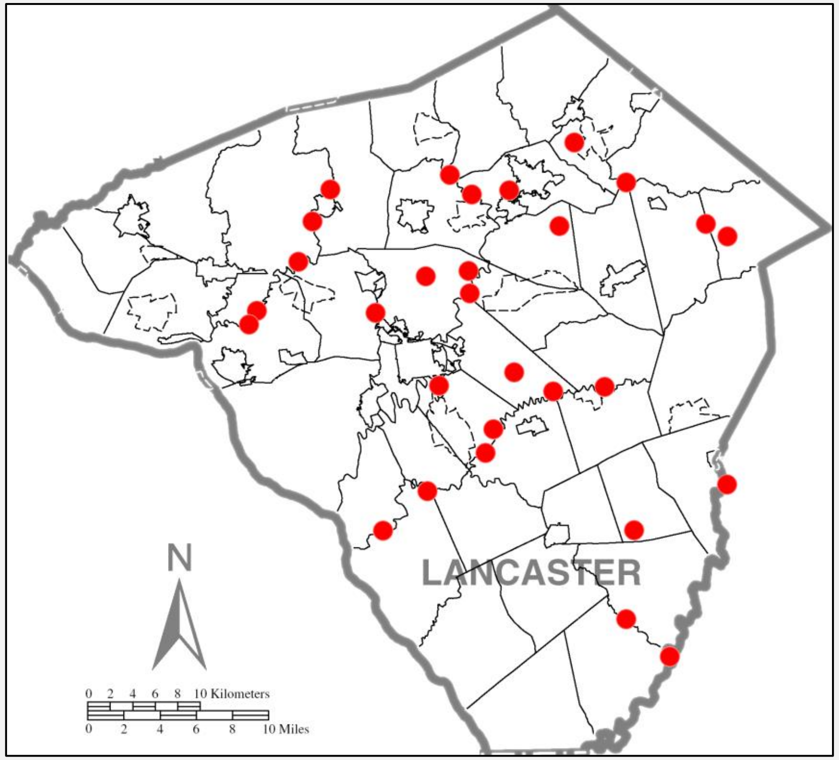
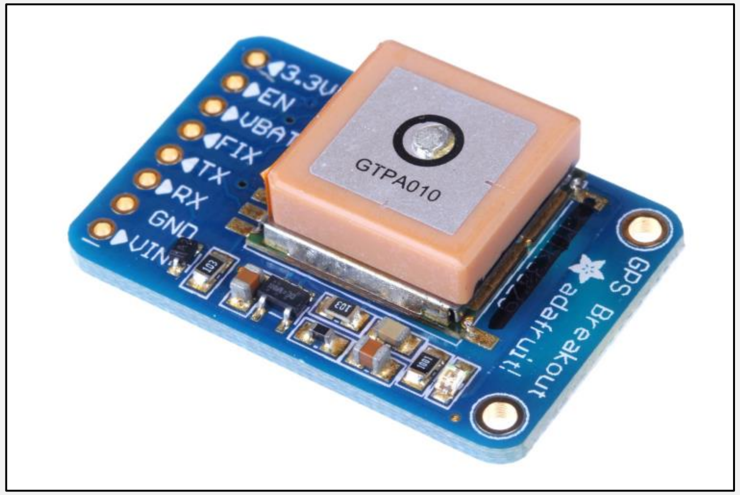
SOUS VID(IOT)


Cooking
Fluorine Stats
Relay
1
0
Relay
1
Temperature (C)
15.5
0
Temperature (C)
100
Temperature (F)
59.900000000000006
0
Temperature (F)
200
Fluorine Control
Fluorine Enable
Set Temp C Input
54
ON
OFF


Crock-Pot
Stoneware Slow Cooker
Low
High
Off
Warm
SONOFF

WIFINDER

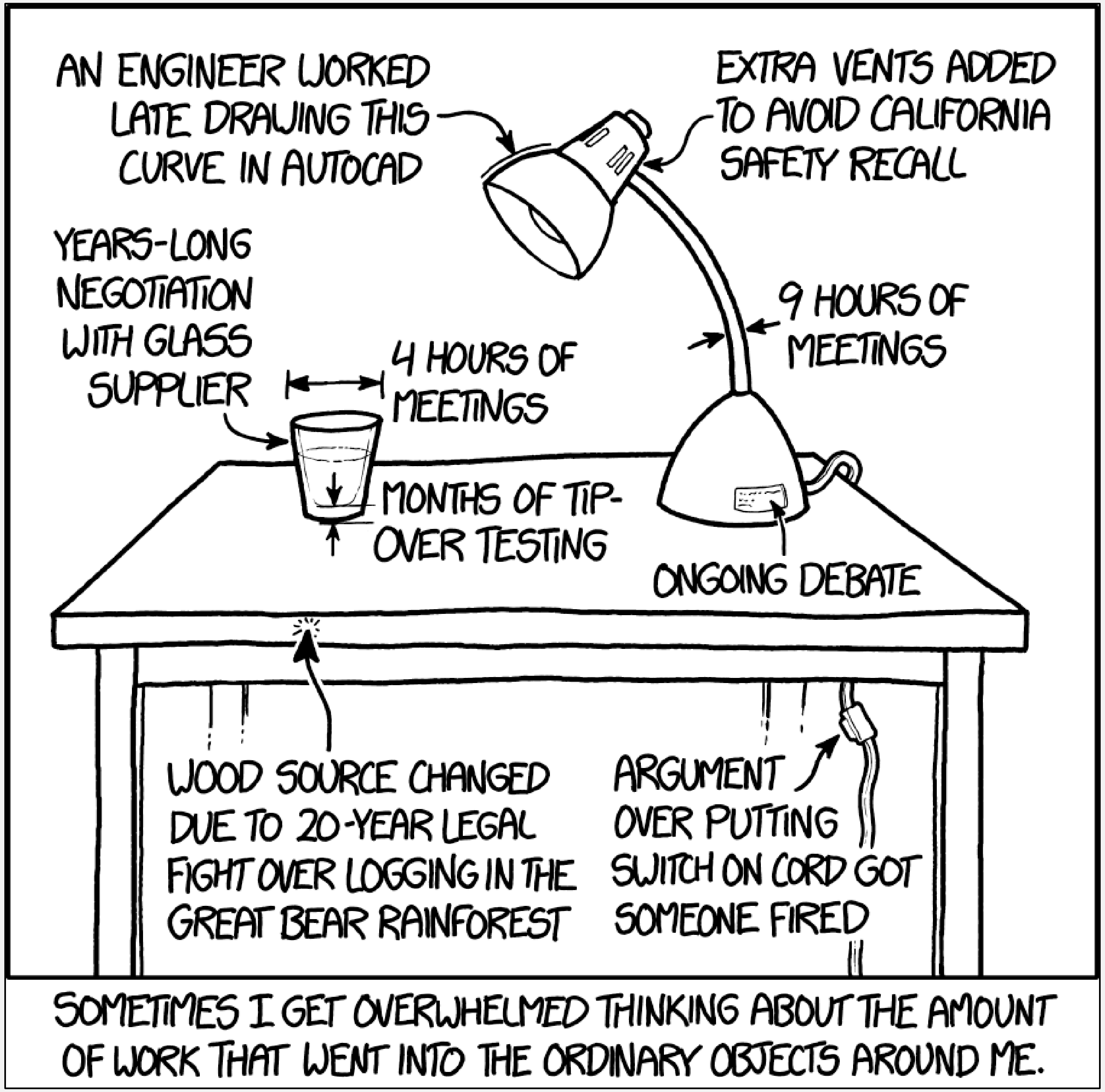

N
LANCASTER
0 2 4 6 8 10 Kilometers
0 2 4 6 8 10 Miles


3.3V
EN
VBAT
FIX
TX
RX
GND
VIN
GTPA010
GPS Breakout
adafruit!

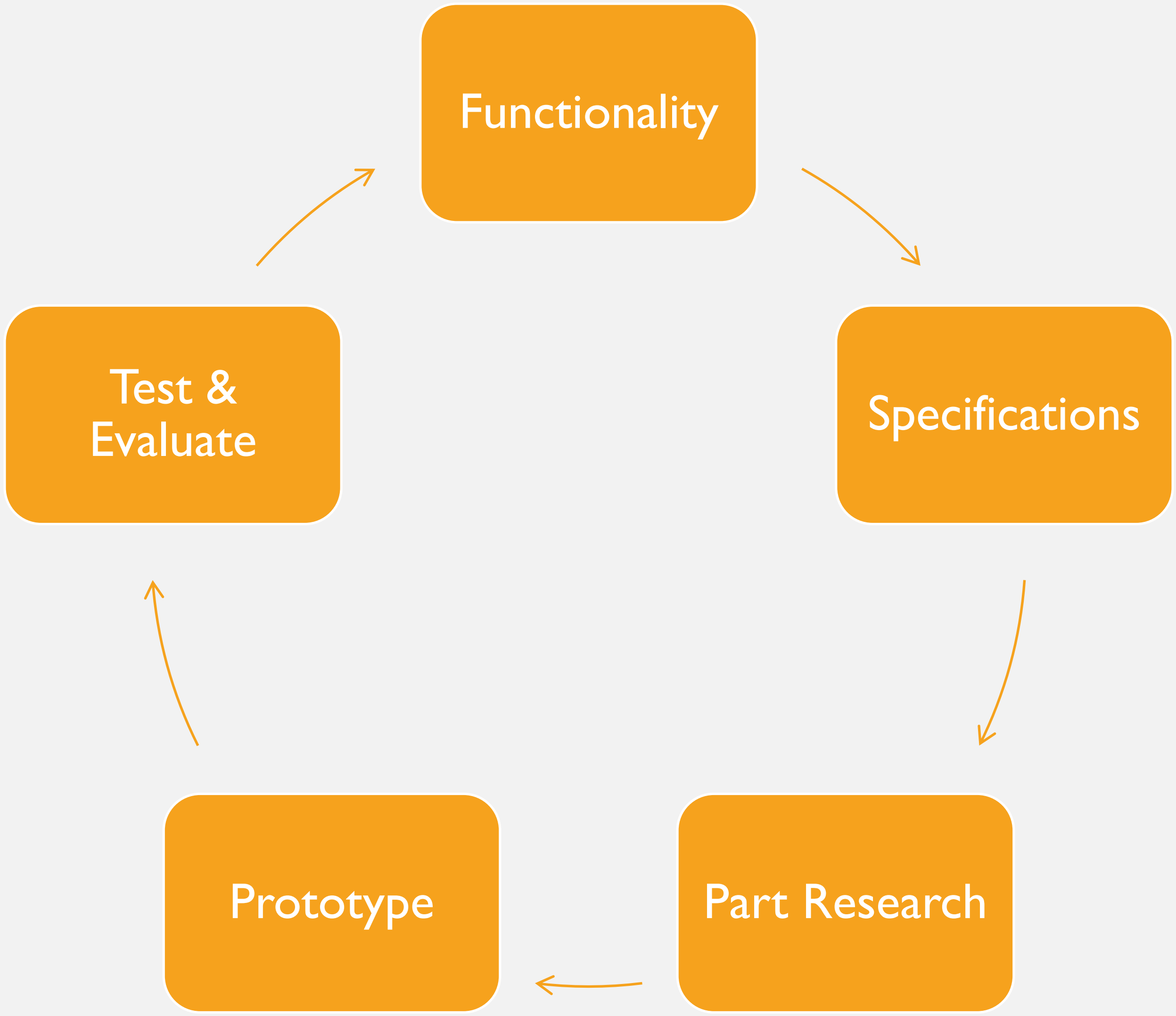
PRODUCT DESIGN CYCLE

How we build amazing products and improve them over time

PRODUCT DESIGN TAKES TIME

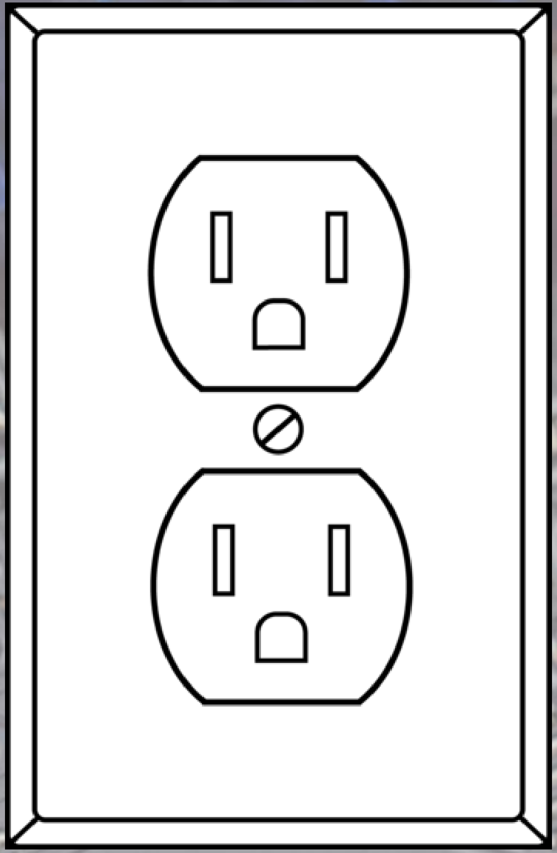


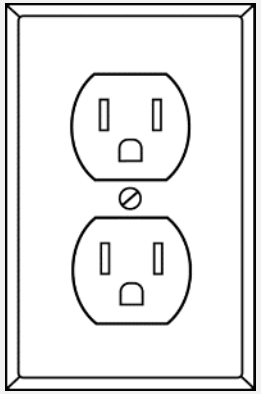
PRODUCT DESIGN CYCLE*



*Though we'll be focusing on the electrical engineering, mechanical, industrial, and human factors design is critical to making a cohesive product.

LET’S BUILD A “SMART OUTLET”





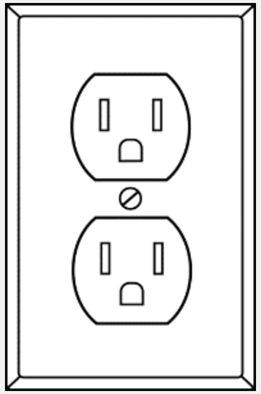
I. FUNCTIONALITY

INDUSTRY

- Device functionality includes the high level actions of the device
  - Your customer will provide most of these details.
  - You, as the experienced designer, should ask usage questions.
- It may, but need not, include technical details.
  - Example: This smart outlet must be safe for USA.
  - Example: This smart outlet handle 30A of power in every country.

COURSE RELATED

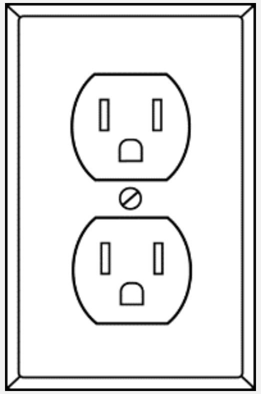
- A0 challenges you to design your high level device concept.
- What's the killer feature(s) of your application?



I. FUNCTIONALITY

FUNCTIONALITY

- Must communicate over WiFi
- Must turn off and on the two outlets independently
- Must implement scheduling capability
- Must be easy to set up through an app
- Must work in every country
- Must be safe for unattended use



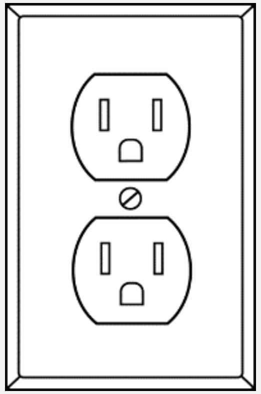
2. SPECIFICATIONS

INDUSTRY

- Device specifications translate device functionality into engineering terms & values.
- Creating a device specifications document puts you and your client on the same page.
  - They'll know what to expect and agree with your plan before you start your work.
- Now's the time to worry about certification as well – UL, FCC, CE, etc.

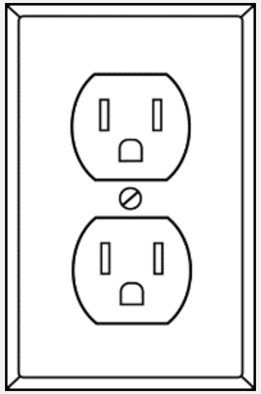
COURSE RELATED

- A0, A1, A2 all relate to device specifications.
- A0 requires a system level diagram
- Anticipated power budget, cost estimate, specifications on the sensors and actuators.
- **Our accelerated design cycle means that specs won't have to be hard and fast!**



2. SPECIFICATIONS

- As an **expert** EE, you should make suggestions.
  - For example, you might recommend having a different smart outlet for the USA & Europe so that cheaper components could be used.
- Protects your team from "feature creep."
  - If something is out of the scope of the work originally specified, you can have another discussion with the client to resolve this issue – either getting paid more, or skipping the desired additional functionality.
- Give a "yes" or "no" answer when tested
  - Does the device function in the range of 110-240VAC at 30A?
  - Is scheduling time accurate within +/-30 seconds?



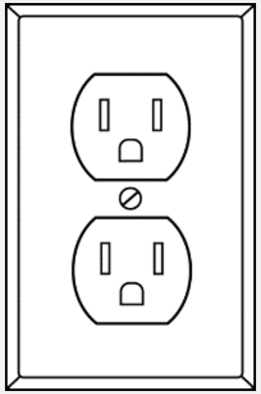
2. SPECIFICATIONS

FUNCTIONALITY

- Must communicate over WiFi
- Must turn off and on the two outlets independently
- Must implement scheduling capability
- Must be easy to set up through an app
- Must work in every country
- Must be safe

SPECIFICATIONS

- Must use 2.4GHz WiFi
- Must implement two separate actuators, controlled separately
- Must sync time accurately down to 1 min
- Must implement WiFi Access Point with captive portal
- Must run on voltages ranging from 110-240VAC up to 30A per outlet
- Must implement surge protection & thermal fuses for failsafe modes



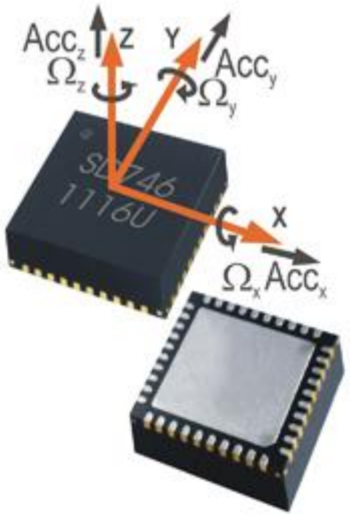
3. PART RESEARCH

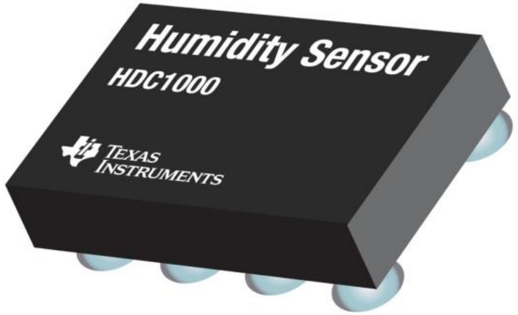
INDUSTRY

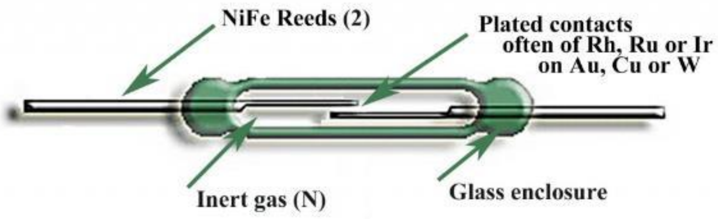
- Components selected based on specifications.
- Create a Bill Of Materials (BOM), which includes all of the necessary components for the PCB.
  - This is updated throughout the project.
- If device power consumption is important, a comprehensive Power Budget will be created.
  - This is important for battery powered devices.
  - This determines the power circuit requirements – ex: will a 1A, 5V supply be enough?
- Sometimes, multiple design options are presented to the client for a final decision. Cost and form factor are important drivers.

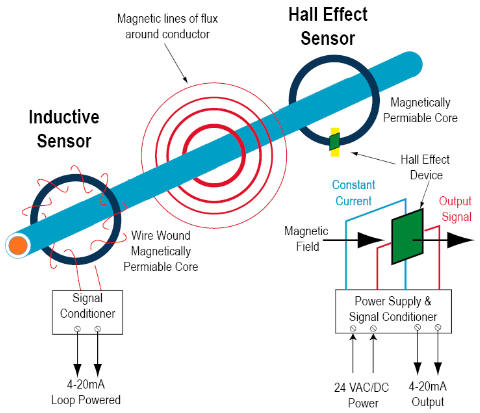
COURSE RELATED

- A1 addresses BOM & power budget.
- A recommended part list is provided for power, sensor, and actuator.
- Groups may choose "a la cart" for components, which may require more work.



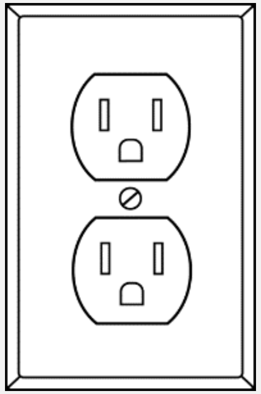






3. PART RESEARCH

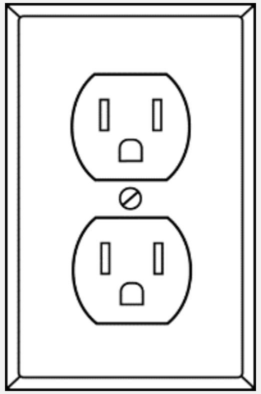
- Identify integration & implementation issues before they happen.
- Cost, power, and voltage level are big considerations.



3. PART RESEARCH

Part	Component	Cost @ 10kQ	Sleep Power (uA)	Wake Power (uA)
MCU + WiFi	SAM W25	$1.83	0.27	2816
Triac	MOC3023S-TA1	$0.20	250	5000
Current Sensor	ACS711	$0.59	100	5500
LED	LTST-C191KFKT	$0.05	100	20000

- Bill Of Materials & Power Budget can be merged into one sheet
- For battery powered devices, a rough consumption calculation is made based on the expected sleep & wake times for the device.
- Quiescent current is important for sleep calculations



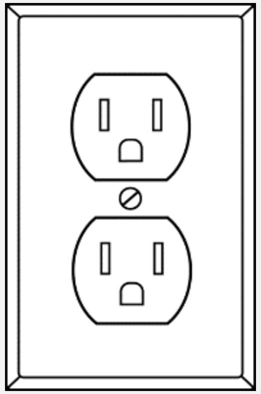
4. PROTOTYPE

INDUSTRY

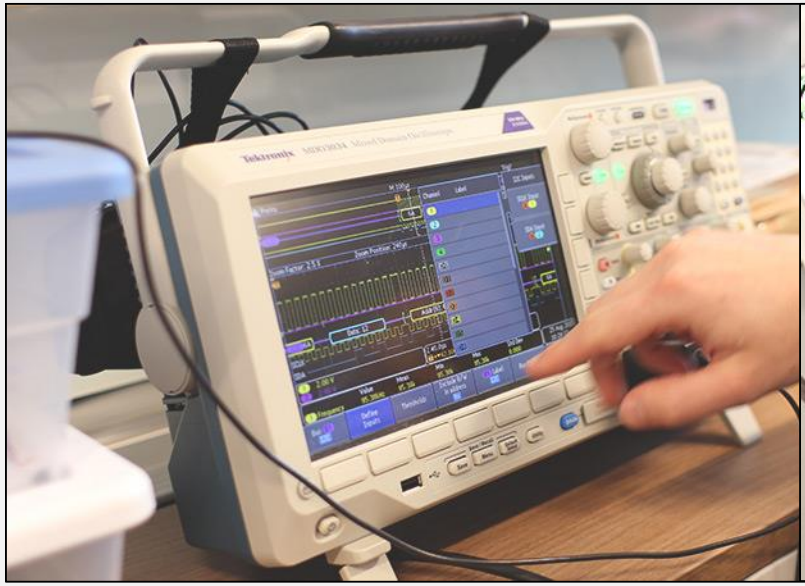
- Prototyping usually consists of multiple sub-phases
  - **Breadboarding**: using development boards to determine functionality and component fit. Get the surprises out beforehand, and get the basics working.
  - **Alpha Prototype**: The first looks like, works like prototype. Has the same form factor as the final product and is used for understanding all issues.
  - **Beta Prototype** : The second looks like, works like prototype. This solves the issues found in the Alpha Prototype. Depending on the complexity of the final product, this would be the last prototype. It is quite close to production ready.

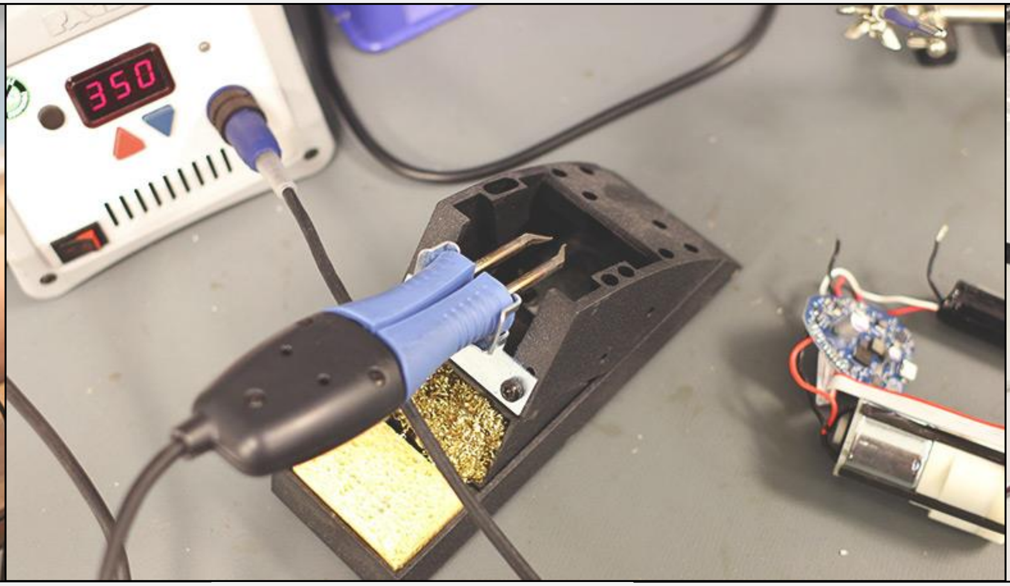
COURSE RELATED

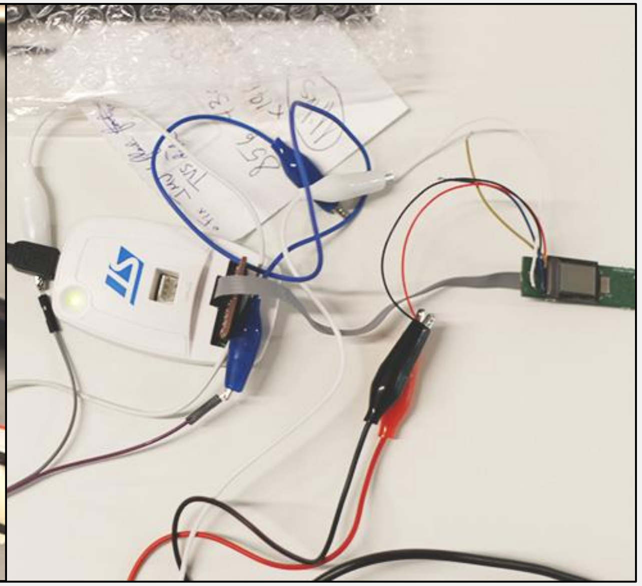
- A1 & A2 will give access to breadboarding for critical components – the power, sensors, and actuators for the devices.
- The remainder of the course can be thought of an alpha prototype development.

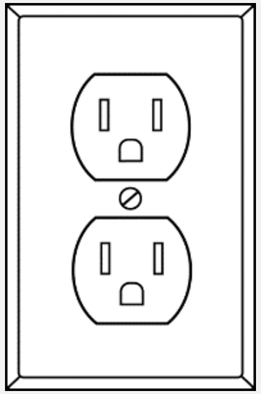


4. PROTOTYPE









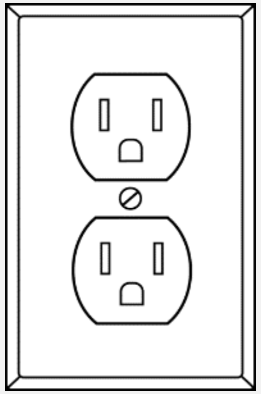
5. TEST & EVALUATE

INDUSTRY

- Create a test plan to validate all critical specifications.
- Identifying bugs in a prototype can be tricky
  - Both firmware and hardware are suspect.
  - Best to use version control (Git, SVN) to manage digital information
  - Important to keep track of both hardware serial number & firmware revision number

COURSE RELATED

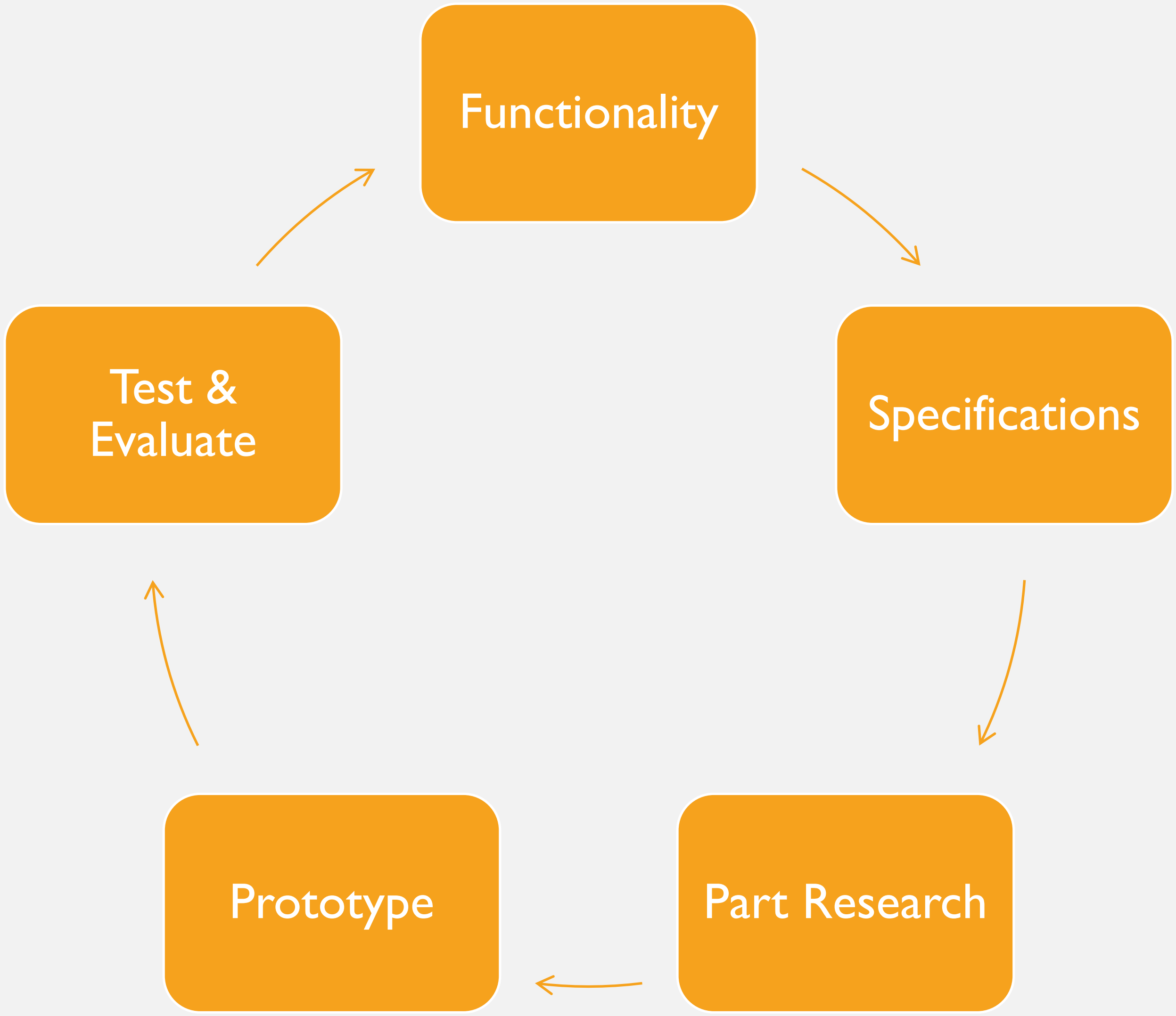
- A10 will be PCB bring-up – the system check of the newly arrived PCB.
- The remainder of the semester will be testing and modifying firmware to complete the project.



5. TEST & EVALUATE

ESE680A-2017S			**Total Tests:**	6	**# Failed:**	3			
Alpha Device Test Plan			**Total Passed:**	3	**# Untested:**	0			
			% Complete:	50%					
Item	**Description**	**Spec**	**Result**	**Status (P/F)**	**SW Ver**	**SN**	**Tester**	**Date**	**Comments**
1	**Power**	---	---	---	---	---	---	---	---
1.01	Outlet switches 110VAC power at 30A?	Turns on & off	Turned on & off	PASS	1	2 & 4	NM	1/12/17	
1.02	Outlet switches 240VAC power at 30A?	Turns on & off	Did not turn off	FAIL	1	2 & 3	NM	1/12/17	Check the variac output
2	**Actuator**	---	---	---	---	---	---	---	---
2.01	Actuator is turned on and off at 100ms intervals	Fails open	Failed open	PASS	1	3 & 4	VS	1/12/17	
2.02	Actuator is exposed to power outside device limits	Fails open	Failed open	PASS	1	1	NS	1/12/17	
3	**Wireless**	---	---	---	---	---	---	---	---
3.01	Device creates an Access Point when it cannot connect to Internet	WiFi AP created	No AP created	FAIL	1	4	VS	1/12/17	Issue with the WiFi library
3.02	Device uses WiFi credentials to successfully connect to router	Connects to router	Did not connect	FAIL	1	4	VS	1/12/17	Potentially incorrect security type

PRODUCT DESIGN CYCLE*



*Though we'll be focusing on the electrical engineering, mechanical, industrial, and human factors design is critical to making a cohesive product.

A0: GROUPS, CONCEPT, HIGH LEVEL

Assigned on Thursday, 1/17

Due by Wednesday, 1/23 @ 7pm

Grade: 100 points

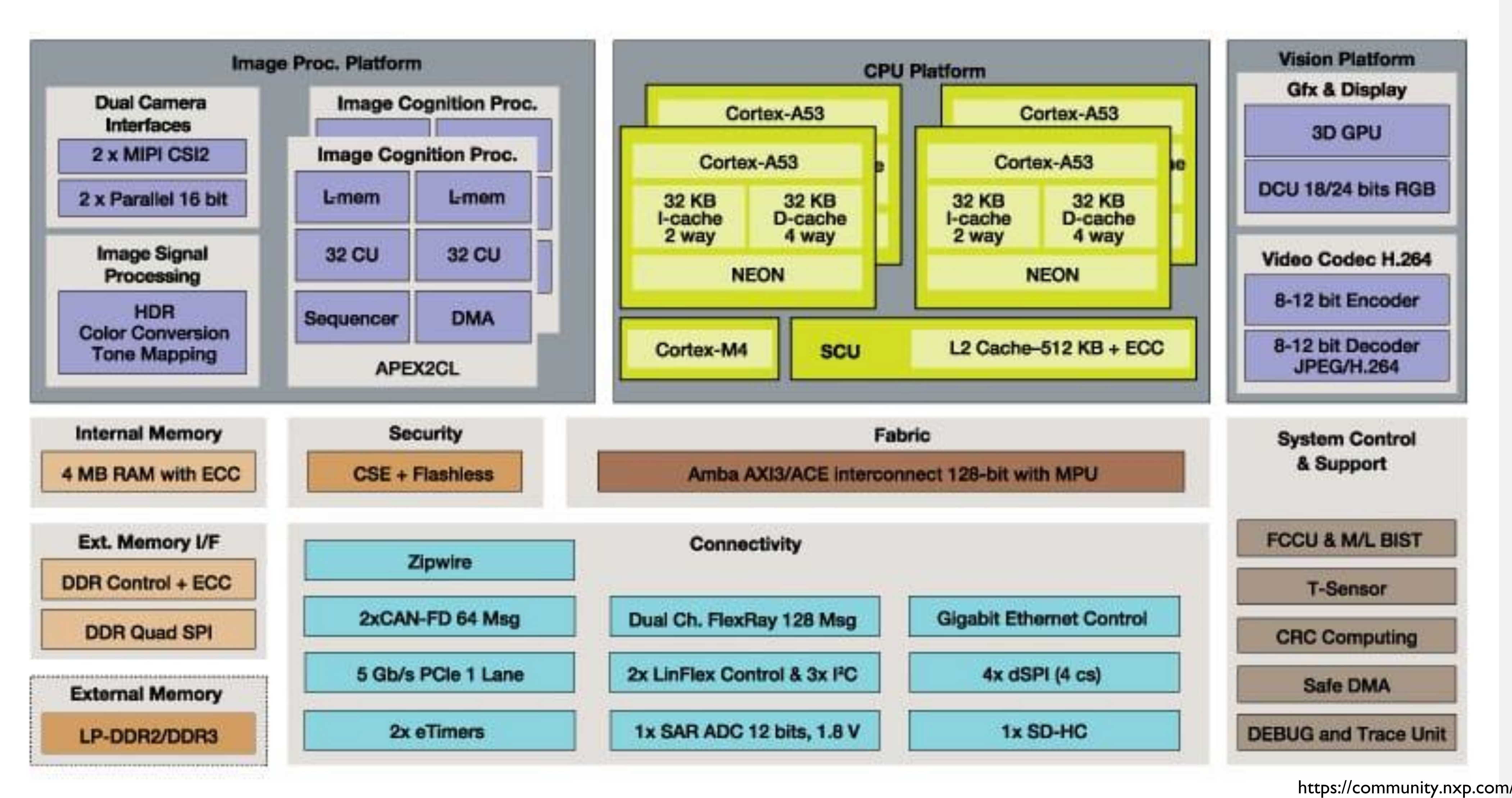
- Create an IoT concept, complete with a high-level diagram including the sensors, actuators, and communication protocols.
- Acclimate to the administrative + design environments.
- More details in **a0** doc in shared Google Drive.
  - To be sent by email Thursday
- Details to be sent later. But start brainstorming ideas!
- This is an individual submission!

CIRCUIT BLOCK DIAGRAM

BLOCK DIAGRAMS

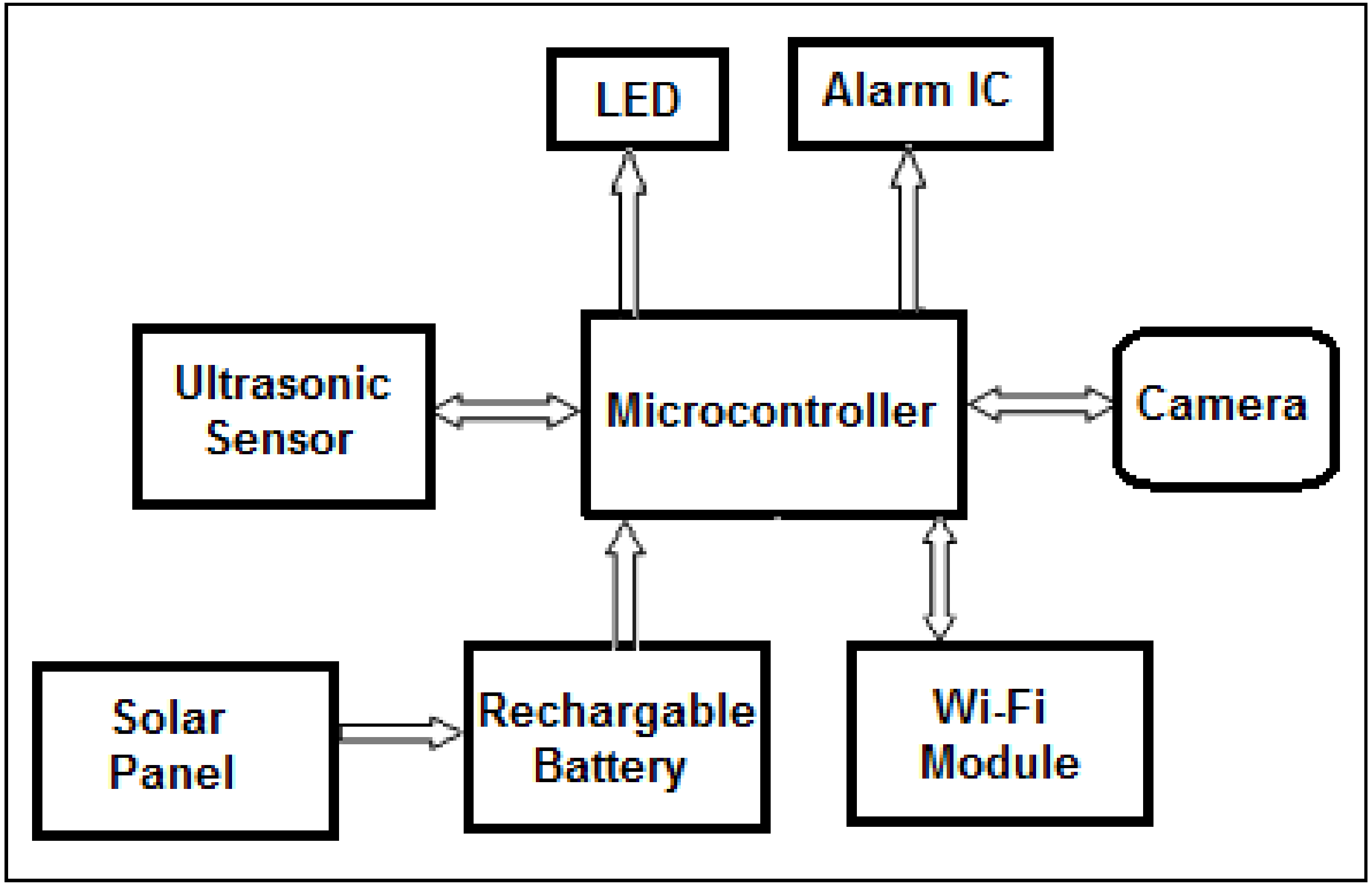
- Provides clarity of design with minimal effort
- Critical for high level client discussions
- Different Levels of information
- Captures enough information for intelligent design discussion
- A good flow is from left (inputs / sensors) to right (outputs / actuators)

SYSTEM DIAGRAM



https://community.nxp.com/docs/DOC-335015

CIRCUIT BLOCK DIAGRAM (SIMPLE)



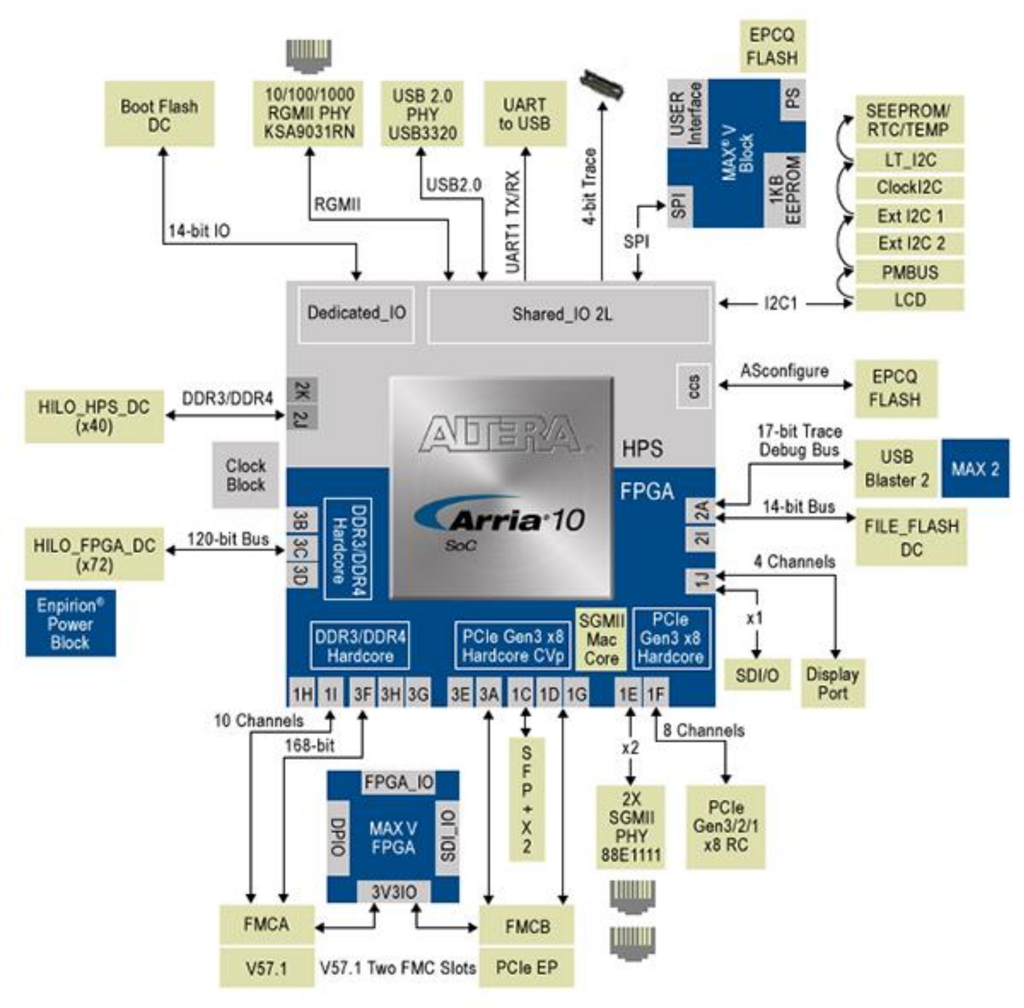
CIRCUIT BLOCK DIAGRAM (DETAILS)

Ask yourself:

What information do I want to focus on?

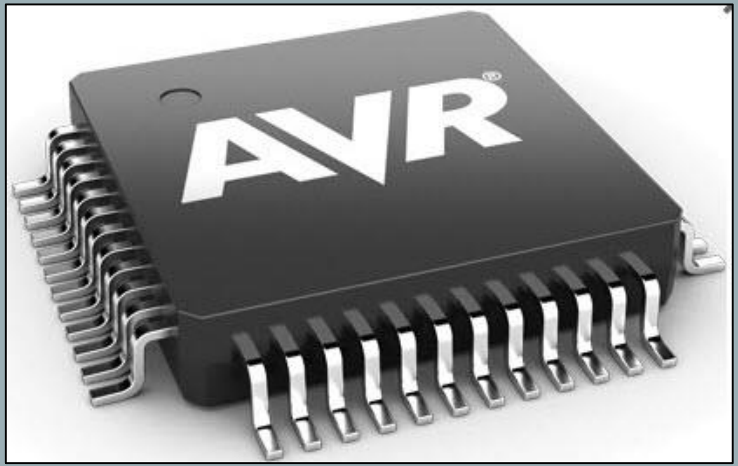
- Communications?
- Component Interactions?
- MCU Peripherals?

- Ask yourself also:
  - Who is your audience?
  - What is their technical knowledge?
  - What do they want to learn from the diagram?



THINGS TO CONSIDER…

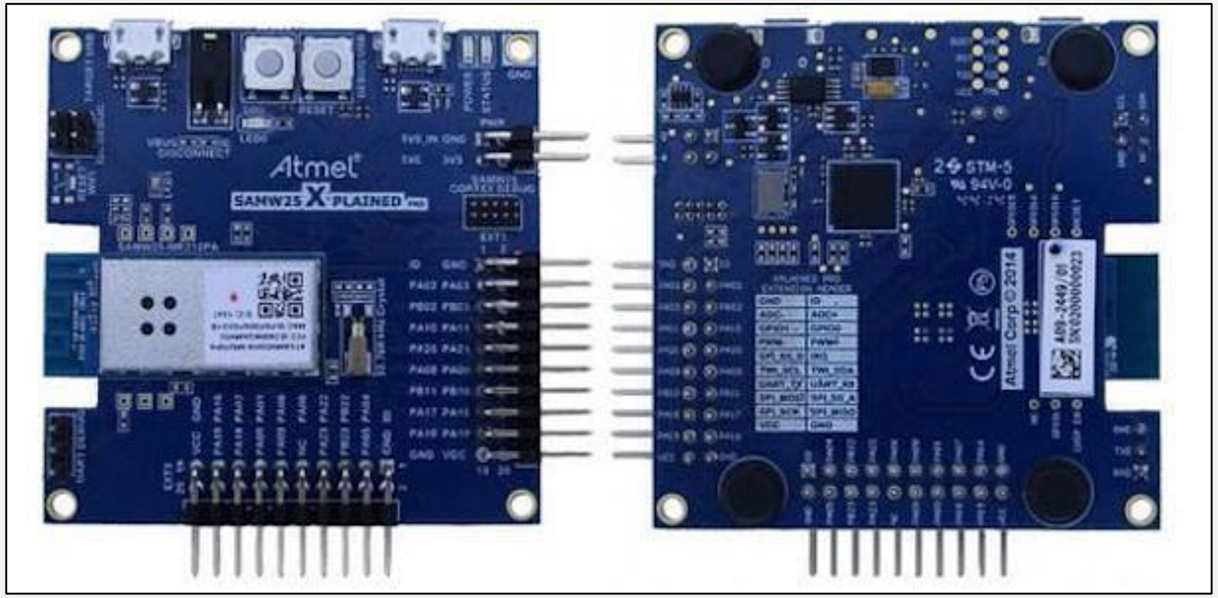
HOW TO CHOOSE AN MCU

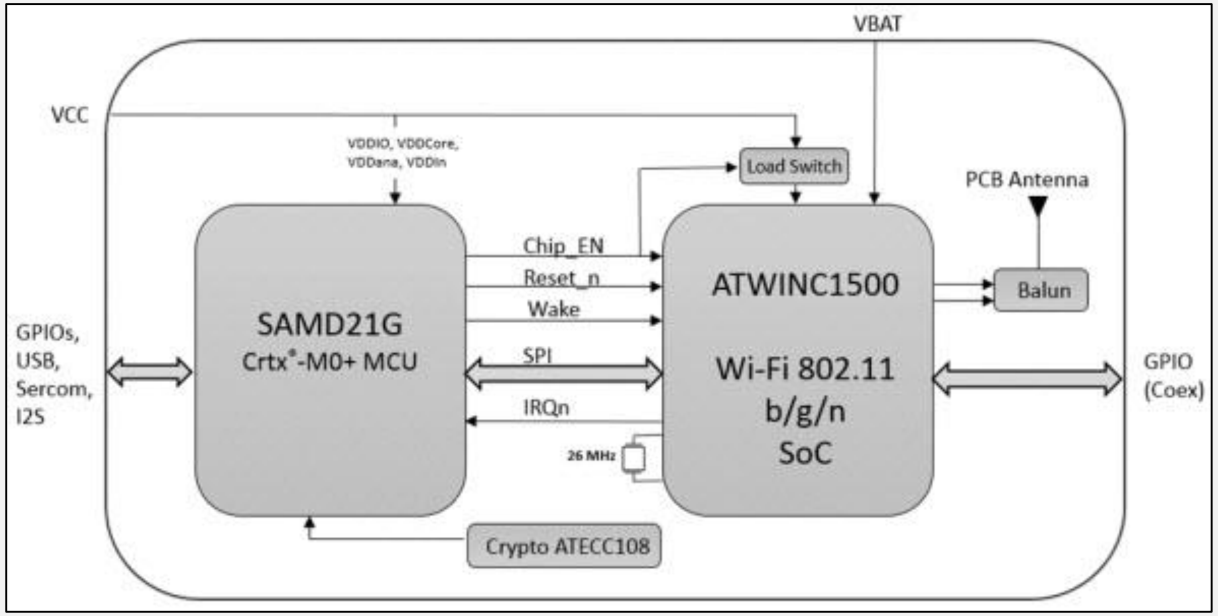


- Availability
  - Is the device in production?
  - What is the lead time for parts in quantity?
- Development environment
  - Examples & libraries go a long way!
  - Licenses can be costly for IAR & Keil
- Peripheral interfaces
  - How must you communicate with your sensors and actuators?
  - I2C, UART, SPI, USB, ADC, I2S
- Processing power
  - How much simultaneous processing?
  - Floating point computation?
  - Real-Time Operating System?
- Memory constraints
  - Higher cost for more flash & RAM
  - Compile an example project to ballpark size.
- Price

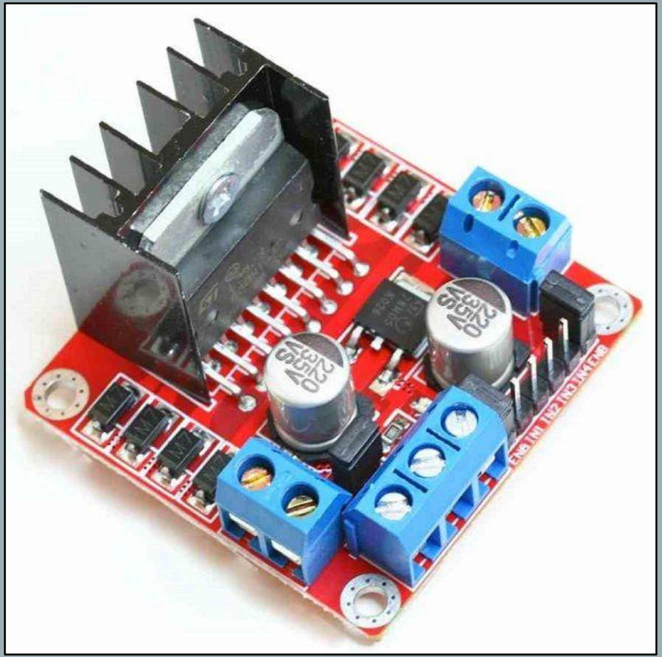
SAM W25

- It's a **module** that combines:
  - **SAMD21:** Cortex M0+
  - **ATWINC1500:** WiFi
  - **ATECC108:** Hardware crypto chip
- FCC certified!
- We'll be testing with a SAMW25 Xplained development board
  - This dev board includes an EDBG chip, allowing flashing and debugging with Atmel Studio



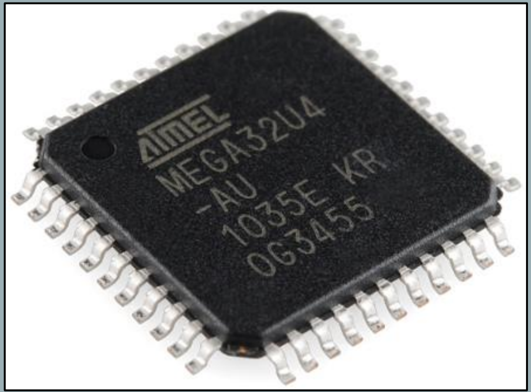


HOW TO CHOOSE PERIPHERALS



- Power consumption
  - Sleep mode vs. active mode
  - Can an interrupt wake up the processor?
- Operating voltage
  - I/O voltage & supply voltage can be different
  - What's considered a "1 / HIGH"? "0 / LOW"?
  - Absolute max and mins?
- Support
  - Libraries or example projects
  - Example application circuits
  - Development boards
- Environmental
  - Temperature, Humidity, Shock, ESD, Moisture
- Thermal dissipation
  - Motor drivers, high end processors
- Many more limitations based on the particular peripheral

MECHANICAL



- Application environment
  - Extreme temperatures
  - High humidity
  - Shaking or dropping
  - Radiation (satellites!)

- Workability
  - Are the component footprints common and simple to solder and rework?
  - BGAs and LGAs are very difficult to rework
  - Distance between pins – the pitch

- Will the footprint make PCB routing more difficult and increase fabrication cost?

- Enclosure challenges?
  - Casework size and shape

- Special mounting for sensors to interact with the environment?

DATASHEETS – READ THEM!

Operating voltage range

Power consumption

Pin descriptions

Application circuit

…

Everything you need!

4 Electrical Specifications

4.1 Absolute Ratings

All typical values are measured at T = 25°C unless otherwise specified. All minimum and maximum values are valid across operating temperature and voltage unless otherwise specified.

Table 4-1. Absolute Maximum Ratings

Parameters	Minimum	Maximum	Unit
VBAT power supply voltage	0	5.0	V
VCC power supply voltage	0	3.63	
Pin voltage with respect to GND and VCC	GND-0.3	VCC+0.3	
Storage temperature range	-40	+125	°C

Table 4-2. General Operating Ratings

Parameters	Minimum	Typical	Maximum	Unit
VBATT	3.0	3.6	4.3	°C
VCC	2.7	3.30	3.6	
Operating temperature range	-40	25	85	

Table 4-3. Physical Characteristics

Parameters	Value	Comments
Size	33.863 x 14.882mm	-
Connector pins pitch	See module footprint	-

Table 4-4. I/O Pins Characteristics

Characteristic	Minimum	Typical	Maximum	Unit
Input Low Voltage V_{IL}	-0.30		0.65	V
Input High Voltage V_{IH}	VCC-0.60		VCC+0.30	
Output Low Voltage V_{OL}			0.45	
Output High Voltage V_{OH}	VCC-0.50			
Output Loading			20	pF
Digital Input Load			6	
Pull-up Resistor	76K	90K	104K	Ω

I/O pin characteristics for pins 5, 45, 46, and 47 (for all other I/O, see the SAM D21G datasheet).

REVISION CONTROL

- Critical for stable code and incremental improvement.
- Testing should note revision numbers
- Code should only be released to clients after unit testing & bug sequestering
- Generated files (generally) are not stored in revision control.
  - Only the source is stored, which can be later used to generate the output files.

- Highly recommended to use for class!

GET STARTED ON A0!

- We’ll spend the remainder of thinking of concepts.
  - These slides will be in a Google Drive folder!

- Start ideating your concept
- Suggested sensors and actuators will be in the Google Drive folder

- Now is the time to see me about any issues, or if you’re not registered!